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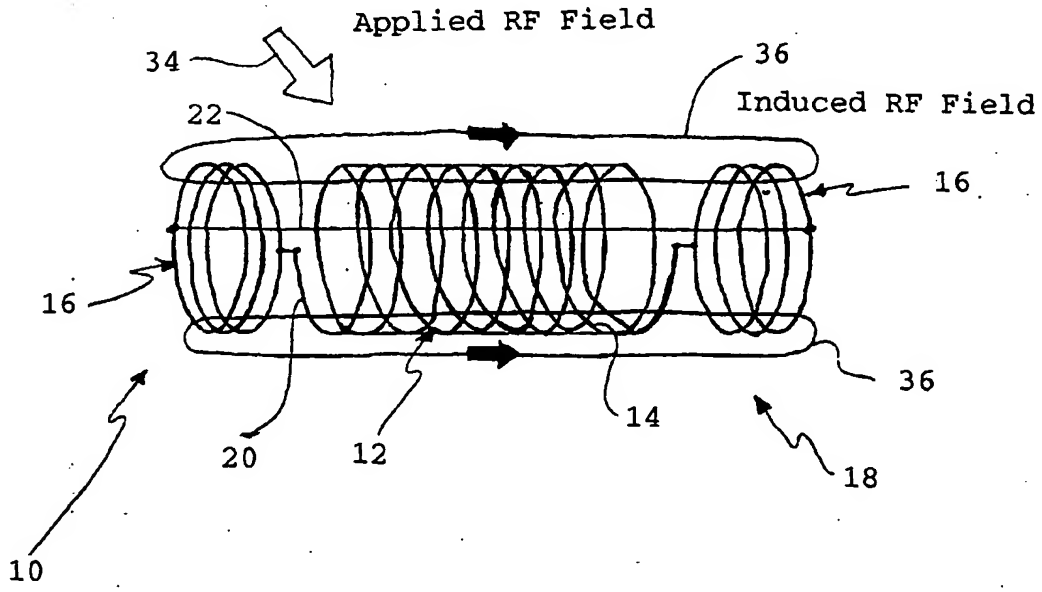
(54) Title: MRI STENT



(57) Abstract: A stent device (10) includes a helical structure (12) and a ring structure (16) connected to the helical structure (12). The ring structure includes an inner conducting ring (24), an outer conducting ring (26), and a dielectric material (28) disposed between the inner (24) and outer (26) conducting rings. The stent device (10) radiates an induced electromagnetic field when subjected to an applied electromagnetic field.

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MRI STENT

BACKGROUND OF THE INVENTION

Cross-reference to Related Application

This patent application claims benefit of patent application U.S. Serial number 09/685,098, filed October 11, 2000.

Field of the Invention

This invention relates to a stent used in conjunction with a magnetic resonance (MR) system, and more particularly to a stent which is capable of repeatedly ablating hyperplastic tissue growing around the stent when the stent is subjected to an radiofrequency (RF) electromagnetic field produced by an external scanner, thus preventing blockage of the stent.

Description of the Related Art

Magnetic Resonance (MR) surface resonators are currently used in a variety of clinical and research applications. The purpose of a surface resonator is to provide improved signal-to-noise performance when imaging small regions. Typically, the resonator is placed on the surface of the body over the region of interest. The surface resonator can be used as a transmit/receive antenna, or, as in many applications, the volume resonator (sometimes referred to as a body coil) of the magnetic resonance scanner will be used as the transmit antenna, while the surface resonator acts as the receive antenna to collect the magnetic resonance signal from the desired region alone.

One area of concern when designing magnetic resonance surface resonators for use as receive antennas is the decoupling issue. More specifically, if a surface resonator with the same resonant frequency as the transmit field is placed inside a volume resonator while the volume resonator is transmitting, the surface resonator will receive and retransmit an intense field around itself. This retransmitted field can result in radiofrequency burns to the patient. In order to prevent surface burns, the surface resonator is "decoupled" during the volume resonator transmit procedure. The surface resonator is decoupled by causing its resonant frequency to change during volume resonator transmit. A diode switching circuit is used to add an additional reactive element to the resonant circuit while transmit is taking place. For example, an additional inductor added to a resonant circuit will lower the resonant frequency. When the

resonant frequency of the surface resonator is sufficiently far from the transmit frequency, the surface resonator will not receive and retransmit a signal, and the RF burn hazard is eliminated.

Known treatments for removing or preventing hyperplastic tissue located within an implanted stent body utilize invasive procedures, such as inserting a catheter into the area near the stent. The catheter is designed to include an antenna at its terminal end. The catheter can then be used as a radio frequency transmit path for ablating tissue that could otherwise create blockage within the vessel. However, such invasive procedures are significantly complex, present higher risks of post procedure complications and can be very uncomfortable for the patient. There are also limits on the number of catheter procedures which can be performed on a patient who is more susceptible to a hyperplastic response.

SUMMARY OF THE INVENTION

In one aspect, the invention features a stent device. The stent device includes an electrically conductive helical structure. The stent device also includes an electrically conductive ring structure connected to the helical structure. The ring structure includes an inner conducting ring, an outer conducting ring, and a dielectric material disposed between the inner and outer conducting rings. The helical structure and the

ring structure are arranged to produce an electromagnetic field when subjected to an applied electromagnetic field.

Embodiments may include one or more of the following features. The ring structure is connected to a first end of the helical structure, and further includes a second ring structure connected to a second, opposite end of the helical structure. The inner conducting ring, the outer conducting ring, and the dielectric material disposed between the inner and outer conducting rings are arranged for defining an electrical capacitor. The inner conducting rings of the ring structures are connected to the first end and the second end of the helical structure, respectively, and further include a return path conductor electrically interconnecting the first ring structure and the second ring structure. The return path conductor is connected to the outer conducting ring of each ring structure.

The helical structure defines a solenoidal inductor for conducting an electrical current. The helical structure and the ring structure define an electrically reactive circuit having a resonant frequency. The helical structure and the ring structure produce the electromagnetic field at the resonant frequency. In one configuration, the helical structure and the inner and outer conducting ring of each ring structure are formed from a nickel-titanium alloy. The nickel-titanium alloy comprises about 40% to 60% nickel.

In another aspect, the invention features a stent for implantation into a vessel of a body. The stent includes a

solenoidal inductor formed by a helical wire structure and a capacitor is connected at each end of the inductor. A return path conductor electrically interconnects the capacitors. The inductor and the capacitor are arranged to radiate an electromagnetic field when subjected to an applied electromagnetic field.

Embodiments may include one or more of the following features. Each capacitor includes an inner conducting ring, an outer conducting ring, and a dielectric material disposed between the inner and outer conducting rings. The inner conducting rings of the capacitors are connected to a first end and a second end of the helical wire structure, respectively, and the return path conductor is connected to the outer conducting rings of the capacitors. The conductor is electrically connected in parallel with the capacitors. The inductor, the inner conducting ring and outer conducting ring of each capacitor, and the return path conductor are formed from a nickel-titanium wire structure. The inductor and the capacitors define an electrically reactive circuit having a resonant frequency. The applied electromagnetic field is transmitted by a magnetic resonance transmitter at the resonant frequency. The electrically reactive circuit radiates the electromagnetic field at the resonant frequency.

In another aspect, the invention features an RF reactive stent for implantation into a vessel of a body. The stent includes a solenoidal inductor for conducting an induced current. The inductor is formed from a helical wire structure having a first end and a second end. A first capacitor is connected to the first end of the inductor, and a second capacitor is connected to the

second end of the inductor. A return path conductor electrically interconnects the first capacitor, the second capacitor and the solenoidal inductor as an electrically reactive circuit. The electrically reactive circuit forming the stent has a resonant frequency. The first capacitor, the second capacitor and the solenoidal inductor are arranged to generate an RF field when subjected to an applied RF field at the resonant frequency of the stent.

Embodiments may include one or more of the following features. The first and second capacitors are each formed by a ring structure having an inner conducting ring, an outer conducting ring, and a dielectric material disposed between the inner and outer conducting rings. The inductor, the first and second capacitors, and the return path conductor are coated with an insulating material. In one configuration, the insulating material is a polymer. The inductor, the inner and outer conducting rings of each capacitor, and the return path conductor are formed from a nickel-titanium wire structure.

In another aspect, the invention features a method for ablating tissue surrounding a reactive stent device. The method includes the steps of providing an radiofrequency reactive stent formed from a solenoidal inductor element which is electrically interconnected to a capacitor element. The method also includes implanting the stent within a vessel of a body, and irradiating the stent with an applied radiofrequency field for causing the inductor element and the capacitor element to generate an radiofrequency field in the vessel.

Embodiments may include one or more of the following features. The stent has a resonant frequency and the stent is irradiated by the applied RF field at the resonant frequency. The method includes the step of identifying the resonant frequency associated with the stent after the step of implanting the stent. The radiofrequency field generated by the inductor element and the capacitor element causes heating of tissue forming the vessel. The step of irradiating the stent produces a selected amount of heat sufficient to cause ablation of the tissue, which may be hyperplastic tissue surrounding the stent.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the matter in which the above-recited features, advantages and objects of the invention as well as others which will become clear are attained and can be understood in detail, more particular descriptions and certain embodiments of the invention briefly summarized above are illustrated in the

appended drawings. These drawings form a part of the specification. It is to be noted, however, that the appended drawings illustrate preferred embodiments of the invention and therefore are not to be considered limiting in their scope.

Figure 1 shows a perspective view of the stent device along with the applied radiofrequency field and the induced radiofrequency field according to a preferred embodiment of the present invention.

Figure 2 shows a perspective view of the detailed structure of the stent body.

Figure 3 is a side view of the stent of Figure 2 showing the detailed structure of the capacitor portion of the stent.

Figure 4 is a cross-sectional view of the polymer coated wire forming the stent body.

Figure 5A is a schematic diagram showing the equivalent resonating circuit effected by the structure forming the stent device.

Figure 5B is a schematic diagram showing the equivalent resonating circuit effected by an alternate structure forming the stent device.

Figure 6 is a schematic diagram showing a technique

for determining the resonant frequency of the stent after implantation into the body of a patient.

Figure 7 is a flowchart showing a method for utilizing the stent.

Figure 8 is a diagram showing the electromagnetic field produced by the implanted stent.

DETAILED DESCRIPTION OF THE INVENTION

Turning to FIG. 1, the RF reactive stent is shown. More specifically, the stent 10 includes a solenoidal body 12 having its geometry formed from a conducting wire 20 shaped into a generally helical cylindrical structure. The helical cylinder forming the stent body 12 prevents the collapse of the artery, vessel or passageway within which the stent is implanted, thereby promoting blood flow through the stent 10. The conducting wire 20 is made from a nickel-titanium (NiTi) alloy. The nickel-titanium alloy composition can range from about 40% to 60% nickel with the remaining percentage being titanium. The helical geometry of the solenoidal body 12 also forms an electrical inductor 14 having an inductance L. An electrical capacitor 16 is formed at each end of the inductor 14. The electrical capacitors 16 have capacitance values of C_1 and C_2. A return current path wire 22 connects each capacitor 16 with the inductor 14. As will

be described in greater detail below, the capacitors 16 function to resonate the inductance of the solenoidal inductor 14. The resulting structure forms a resonant circuit 18 (FIG. 5A) which resonates when subjected to an applied radiofrequency electromagnetic field at the resonant frequency of the circuit 18. The applied electromagnetic field is generated at the resonant frequency of the circuit 18 which in turn re-radiates an electromagnetic field causing tissue surrounding the stent 10 to generate heat. This warming feature is described in greater detail below.

Referring briefly to FIG. 5A the equivalent circuit for the stent 10 can be modeled as a parallel LC resonant circuit. More specifically, the equivalent circuit 18 is shown as an inductor L, formed by the solenoidal body 12, in parallel with two capacitors 16 having capacitance values of C_1 and C_2. The resulting device is a parallel inductor/capacitor (LC) circuit 18 having a resonant frequency f_r given by the following formula.

$$f_r = \frac{1}{2\pi\sqrt{L(C/2)}}$$

The stent 10 is described above to include two capacitors 16, each capacitor being connected at one end of the inductor 14. However, as shown in FIG. 5B, the equivalent circuit 18' associated with stent 10 can be alternately configured to include only one capacitor C connected to the inductor L. In this alternate configuration the inner conductor ring 24 is connected to one end of the inductor 14, and the outer conductor ring 26 is connected to the opposite end of the inductor 14 via the return current wire

22. If a single capacitor 16 is used, the resonant frequency f_r is given by:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

in which case the return current path wire 22 is connected to the last coil forming the non-capacitive end of the stent body 12.

The resonant frequency f_r is preferably selected such that it does not correspond to any clinical scanner frequencies, or harmonics thereof. Preferably, the resonant frequency f_r will be established between 50 MHz to 300 MHz exclusive of 10 MHz ranges centered on the resonant frequencies used for clinical MR imaging from 1.5T to 7.0T. Exemplary values for L and C will depend on the size and application of the stent. Possible L and C values for a coronary stent circuit may be L = 1.0 μH, C = 0.5 pF, f_r = 225 MHz wherein the values are in the range of L = 0.3 - 1.2 μH and C = 0.3 - 0.7 pF. Possible L and C values for a carotid stent circuit may be L = 3.0 μH, C = 0.8 pF, f_r = 103 MHz wherein the values are in the range of L = 1.0 - 4.0 μH and C = 0.6 - 1.0 pF.

Referring to FIG. 2, the detailed structure of each capacitor 16 is shown. While only one capacitor 16 is shown in detail, it should be understood that each capacitor 16 is substantially similar in structure. The capacitor 16 formed at each end of the inductor 14 includes an inner conducting ring 24 and a structurally parallel outer conducting ring 26, each formed from the NiTi conducting wire 20. A polymer dielectric ring 28 is disposed between the inner and outer conducting rings 24, 26. The inner conducting ring 24 of each capacitor 16 is electrically

connected to the last coil forming the end of the inductor 14, and preferably forms an integral structure with wire 20 that defines inductor 14. The outer conducting rings 26 of capacitors 16 are electrically interconnected by current path wire 22 thereby completing the LC electrical circuit.

A partial side view of the reactive stent structure 10 is shown in FIG. 3. More particularly, FIG. 3 shows the polymer dielectric ring 28 disposed between the inner and outer capacitive conductors 24, 26 for forming the electrical capacitor 16. The components forming the stent device 10 are also coated with an electrical insulator, in order to confine the induced electric current path to the conducting wire 20 of the stent body 10, and produce the desired radio frequency field geometry. More specifically, all of the NiTi conducting wire 20 forming the inductor 14, the return path conductor 22, and the capacitors 16 formed by the inner and outer conducting rings 24, 26 and the polymer dielectric ring 28, are coated with a suitable polymer material 32.

Turning briefly to FIG. 4, the polymer coated wire 30 forming the structure of the stent device 10 is shown in cross-section. The diameter of the conducting wire 20 is in the range of about 0.007 in. to 0.013 in. As will be appreciated, the polymer coating 32 functions as an electrical insulator around the stent 10. The polymer coating 32 has a thickness in the range of about 50 to 400 microns. The polymer coating 32 can be applied by deposition techniques or by dipping, depending on the thickness and mechanical properties desired.

Referring back to FIG. 1, the functional aspects of the stent device 10 are described in more detail. In operation, when the stent device 10 is subjected to an applied RF field 34, the geometry of the inductor 14 and the capacitors 16 produces an intense induced radiofrequency field 36 around itself at the resonant frequency f_r. In order to generate the proper field geometry it is preferred that the electrical path be solenoidal. As such, this geometry allows for a highly focused induced radiofrequency field 36 near the stent body 12 that causes the tissue itself such as endothelial tissue in the immediate region of the stent 10 to generate heat by absorption of radiofrequency energy. This heating effect is responsible for the ablation of hyperplastic tissue around or within the stent 10.

Once in place, for example within an artery, the radiofrequency reactive stent device 10 is excited by placing the subject in a resonator designed for driving the stent 10 at its self-resonant frequency f_r. The transmitter of the resonator is turned on at a specific power level for a specified duration and transmits an RF signal at the resonant frequency of the stent device 10, causing the stent device 10 to resonate and produce the desired heating effect in the tissue. The stent device 10 functions to "receive" the radiofrequency signal and re-radiate an intense induced field 36 at the resonant frequency into its immediate surroundings. Absorption of RF energy from the re-radiated field by the vascular endothelium is intended to raise the temperature of the surrounding endothelial tissue to approximately 60°C. This temperature increase serves to ablate the surrounding tissue and to prevent further proliferation of the endothelial cells. The

radiofrequency transmitter for generating the applied field 34 preferably includes a frequency source, an radiofrequency amplifier, and a resonator for producing the electro-magnetic field. The resonator resembles an MR volume resonator and is driven by an radiofrequency amplifier of 500-1000W output. An radiofrequency synthesizer is used as an adjustable frequency source in order to provide a signal at the resonant frequency f_r of the implanted stent, which is then amplified and fed to the resonator.

As will be appreciated by one skilled in the art, it is important to know the exact resonant frequency of the stent 10 once it is implanted within the body. This is because the resonant frequency of the stent 10 will likely shift or change slightly after being implanted. Reasons for a resonant frequency shift include mechanical deformation of the stent, electric field losses in the conducting medium of blood and tissue, and dielectric effects of blood and tissue.

Determining the resonant frequency is accomplished using an inductive coupling technique, and preferably using a device known as a "dip meter". This technique is described further with respect to FIG. 6. More specifically, FIG. 6 shows the stent 10 implanted within a patient's body 42. When the inductive loop 40 of the dip meter 38 is placed in proximity to a resonant circuit, such as the circuit 18 formed by the stent 10, and the meter 38 is tuned to the resonant frequency of the circuit 18, resonance is indicated by a change in the bias current of the oscillator associated with the dip meter 38, seen as a "dip" on the

current meter. Thus, the operating frequency of the dip meter 38 can be varied to identify the unknown resonant frequency of the resonant circuit 18 formed by the stent 10 without physical or direct electrical contact with the stent 10. It should be noted that the applied RF field 34 is not present or utilized during the procedure of determining the resonant frequency of the implanted stent 10 using the dip meter 38. Further, the dip meter 38 is removed from the field of the transmit resonator 44 when the stent is irradiated by the applied radiofrequency field 34.

With reference to FIG. 7, a method for ablating tissue either surrounding or within the stent device 10 is shown at 50. The method includes at 52 the step of providing an RF reactive stent 10 formed from a solenoidal inductor 14 and a capacitor 16 which together define an electrical circuit 18, 18' having a resonant frequency as described above. The stent device 10 is then implanted within a vessel of a body at 54. After the stent device is implanted, the resonant frequency of the stent device 10 is identified at 56. One technique for identifying the resonant frequency is through the use of a dip meter 38 as described above. The implanted stent device 10 is then irradiated at 58 with an applied radiofrequency electromagnetic field at the resonant frequency of the stent 10 which causes the stent to resonate and produce an induced radiofrequency field at the resonant frequency.

Referring to FIG. 8, the stent device 10 is shown as being implanted within a vessel 46 of a body 42. Also shown is

that after the resonant frequency is identified, the stent 10 is irradiated with the applied radiofrequency field 34 at the resonant frequency. As the stent 10 begins resonating, current begins conducting through the inductor 14 and capacitor 16 forming the stent 10, and the induced radiofrequency field 36 is produced. The induced radiofrequency field 36 then causes the tissue surrounding the stent 10 to generate heat for producing the desired ablation effect described above.

The stent device 10 of the present invention includes many advantages over known medical stents. The geometry of the stent device 10 results in the generation of an intense solenoidal radiofrequency electromagnetic field confined primarily to the vascular endothelium. For example, the stent device 10 allows tracking of blood flow post primary stent placement, and determination of any hyperplasic or restenotic response associated with the patient. The same stent device 10 can subsequently be used for producing an ablation field by using specific solenoidal geometry. Because the stent device 10 of the present invention is fully magnetic resonance compatible, the stent 10 can be used for uniformly ablating the endothelium surrounding it, rather than ablating spots, as is currently done with ablation catheterization procedures. Thus, periodic re-ablation can be performed in a completely non-invasive manner.

The NiTi material forming the stent device 10 does not appear to produce any significant artifacting (signal loss) in the resulting magnetic resonance images as do medical stents formed from stainless steel. As a result, the NiTi material allows the

magnetic resonance imaging system to image tissue surrounding the stent 10 and tissue inside the stent 10 without being blocked by the stent body 12. Accordingly, the NiTi structure forming the stent 10 provides many significant advantages over stent geometries formed from stainless steel which typically does not allow tissue within the stent to be imaged.

The stent 10 described herein may be utilized in a variety of therapeutic applications including but not limited to: shunts, shunts used for dialysis, artificial veins, arteries and grafts, esophageal stenosis, esophageal cancer, esophageal varacies, lung bronchi for cancer treatment, urethra, hydrocephalus shunt tubes, trachea, middle ear tubes, lymphatic ducts and grafts, gastrointestinal stenosis and inflammatory diseases (e.g. Crohn's disease), pyloric stenosis, and biliary atresia.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A stent device comprising:

an electrically conductive helical structure; and

an electrically conductive ring structure connected to said helical structure, said ring structure comprising an inner conducting ring, an outer conducting ring, and a dielectric material disposed between said inner and outer conducting rings, wherein the helical structure and the ring structure are arranged to produce an electromagnetic field when subjected to an applied electromagnetic field.

2. The stent device of claim 1, wherein the inner conducting ring, the outer conducting ring, and the dielectric material disposed between said inner and outer conducting rings define an electrical capacitor.

3. The stent device of claim 1, wherein a first ring structure is connected to a first end of said helical structure, and a second ring structure is connected to a second, opposite end of said helical structure

4. The stent device of claim 3, wherein the inner conducting rings of said first and second ring structures are connected to said first and said second end of said helical structure respectively, and further comprising a return path

conductor electrically interconnecting said first ring structure and said second ring structure.

5. The stent device of claim 4, wherein said return path conductor is connected to the outer conducting ring of each of said first and second ring structure.

6. The stent device of claim 1, wherein said helical structure defines a solenoidal inductor for conducting an electrical current.

7. The stent device of claim 1, wherein said helical structure and said ring structure define an electrically reactive circuit having a resonant frequency.

8. The stent device of claim 7, wherein said helical structure and said ring structure produce an electromagnetic field at said resonant frequency.

9. The stent device of claim 1, wherein said helical structure and said inner and outer conducting ring of said ring structure are formed from a nickel-titanium alloy.

10. The stent device of claim 9, wherein said nickel-titanium alloy comprises about 40% to 60% nickel.

11. A stent for implantation into a vessel of a body, comprising:

a solenodial inductor formed by a helical wire structure;

capacitors connected at each end of said inductor; and

a return path conductor electrically interconnecting said capacitors, wherein said inductor and said capacitors are arranged to radiate an electromagnetic field when subjected to an applied electromagnetic field.

12. The stent of claim 11, wherein each of said capacitor comprises an inner conducting ring, an outer conducting ring, and a dielectric material disposed between said inner and outer conducting rings.

13. The stent of claim 12, wherein the inner conducting rings of a first and a second capacitor are connected to a first and a second end of the helical wire structure respectively, and the return path conductor is connected to the outer conducting rings of said capacitors.

14. The stent of claim 11, wherein said inductor is

electrically connected in parallel with said capacitors.

15. The stent of claim 12, wherein the inductor, the inner conducting ring and outer conducting ring of each capacitor, and the return path conductor are formed from a nickel-titanium wire structure.

16. The stent of claim 11, wherein said inductor and said capacitors define an electrically reactive circuit having a resonant frequency.

17. The stent of claim 16, wherein said electrically reactive circuit radiates electromagnetic field at said resonant frequency.

18. The stent of claim 16, wherein an electromagnetic field having said resonant frequency is applied onto said electrically reactive circuit by a magnetic resonance transmitter.

19. An radiofrequency reactive stent for implantation into a vessel of a body, comprising;

a solenoidal inductor for conducting an induced current, said inductor being formed from a helical wire structure

having a first end and a second end;

a first capacitor connected to the first end of said inductor;

a second capacitor connected to the second end of said inductor;

a return path conductor electrically interconnecting said first capacitor, said second capacitor and said solenoidal inductor as an electrically reactive circuit having a resonant frequency, wherein said first capacitor, said second capacitor and said solenoidal inductor are arranged to generate a radiofrequency field when subjected to an applied radiofrequency field at the resonant frequency of the stent.

20. The stent of claim 19, wherein said first capacitor and said second capacitor are each formed by a ring structure comprising an inner conducting ring, an outer conducting ring, and a dielectric material disposed between said inner and outer conducting rings.

21. The stent of claim 19, wherein said inductor, said first and second capacitor, and said return path conductor are coated with an insulating material.

22. The stent of claim 21, wherein said insulating material is selected from the group consisting of natural polymer, synthetic polymer, a ceramic dielectric, a combination of the above three materials, and the same dielectric material as that

disposed between the inner and outer conducting rings of said capacitors.

23. The stent of claim 20, wherein the inductor, the inner and outer conducting ring of each capacitor, and the return path conductor are formed from a nickel-titanium wire structure.

24. A method of ablating tissue surrounding a reactive stent device, comprising the steps of:

providing a radiofrequency reactive stent formed from a solenoidal inductor element electrically interconnected to a capacitor element;

implanting said stent within a vessel of a body; and

irradiating said stent with an applied radiofrequency field to cause said inductor element and said capacitor element to generate a radiofrequency field in said vessel, wherein the radiofrequency field generated in said vessel causes tissue ablation surrounding said stent.

25. The method of claim 24, wherein said capacitor element comprises an inner conducting ring, an outer conducting ring, and a dielectric material disposed between said inner and outer conducting rings.

26. The method of claim 24, wherein said stent has a

resonant frequency and said stent is irradiated by an applied radiofrequency field at the resonant frequency.

27. The method of claim 24, further comprising the step of identifying the resonant frequency associated with the stent after the step of implanting the stent.

28. The method of claim 24, wherein said radiofrequency field generated by said inductor element and said capacitor element causes heating of tissue forming said vessel.

29. The method of claim 24, wherein the step of irradiating said stent device produces a selected amount of heat sufficient to cause ablation of the tissue.

30. The method of claim 24, wherein said tissue is selected from the group consisting of hyperplastic tissue, abnormal tissue and abnormal tissue deposit.

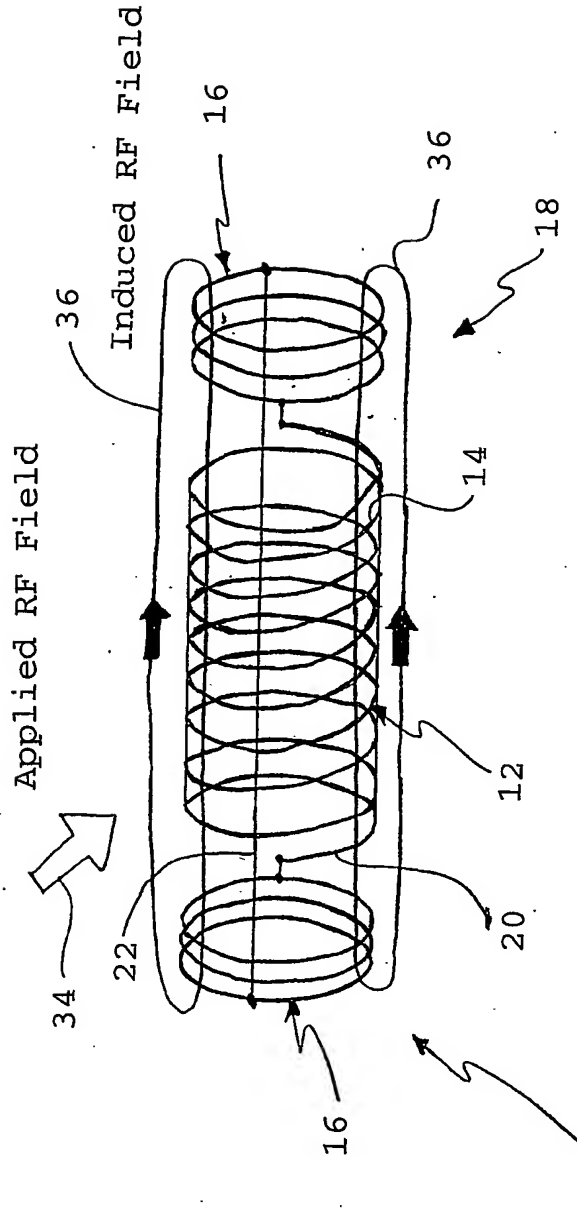

Induced RF Field
16
36
18
36
Applied RF Field
14
12
34
22
20
16
10

Fig. 1

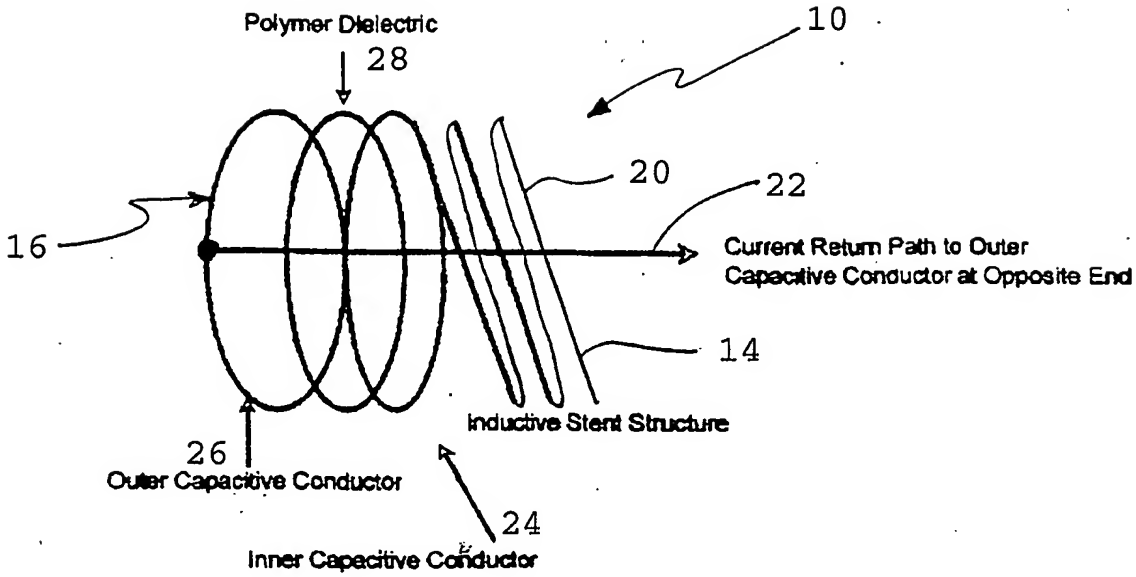
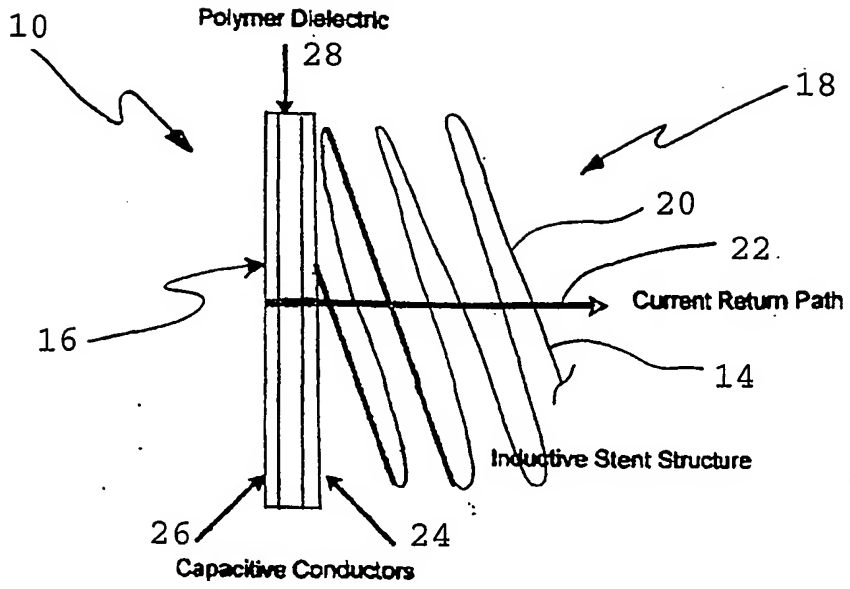

Polymer Dielectric
28
10
20
22
16
Current Return Path to Outer
Capacitive Conductor at Opposite End
14
Inductive Stent Structure
26
Outer Capacitive Conductor
24
Inner Capacitive Conductor

Fig. 2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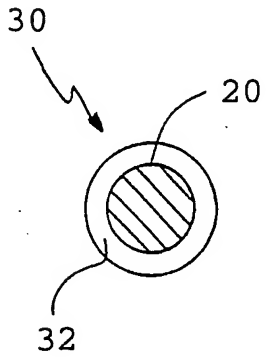
26
24
Capacitive Conductors

Fig. 3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20
32

Fig. 4

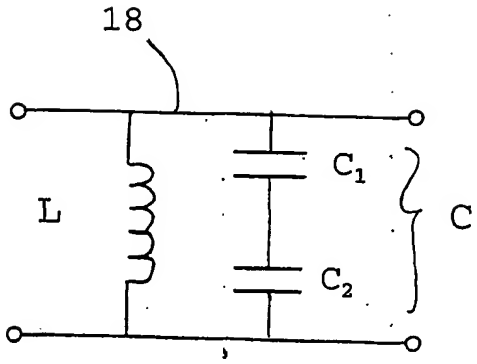

Fig. 5A

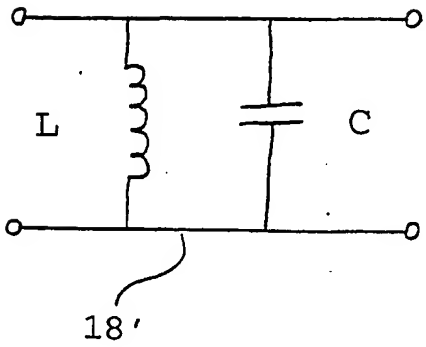

Fig. 5B

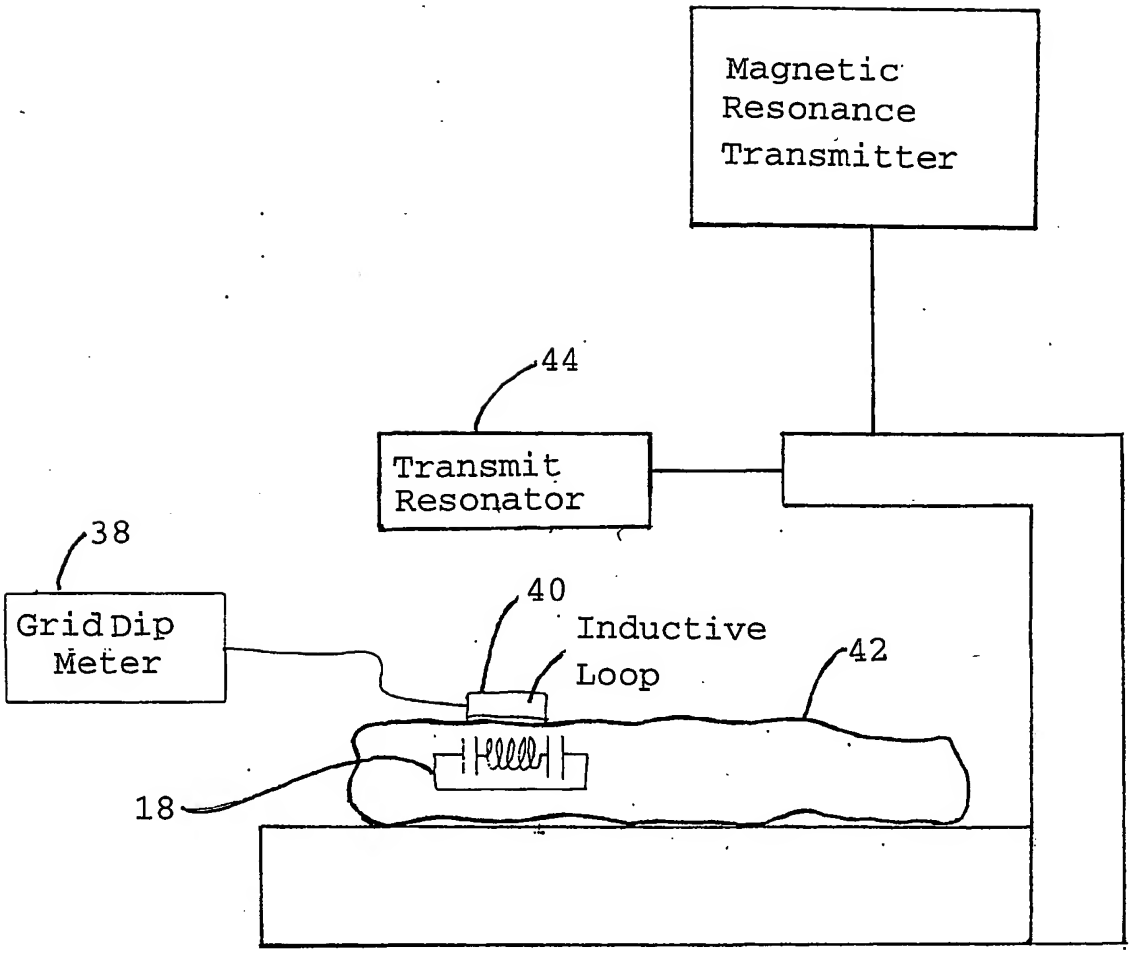
Magnetic
Resonance
Transmitter
44
Transmit
Resonator
38
Grid Dip
Meter
40
Inductive
Loop
42
18

Fig. 6

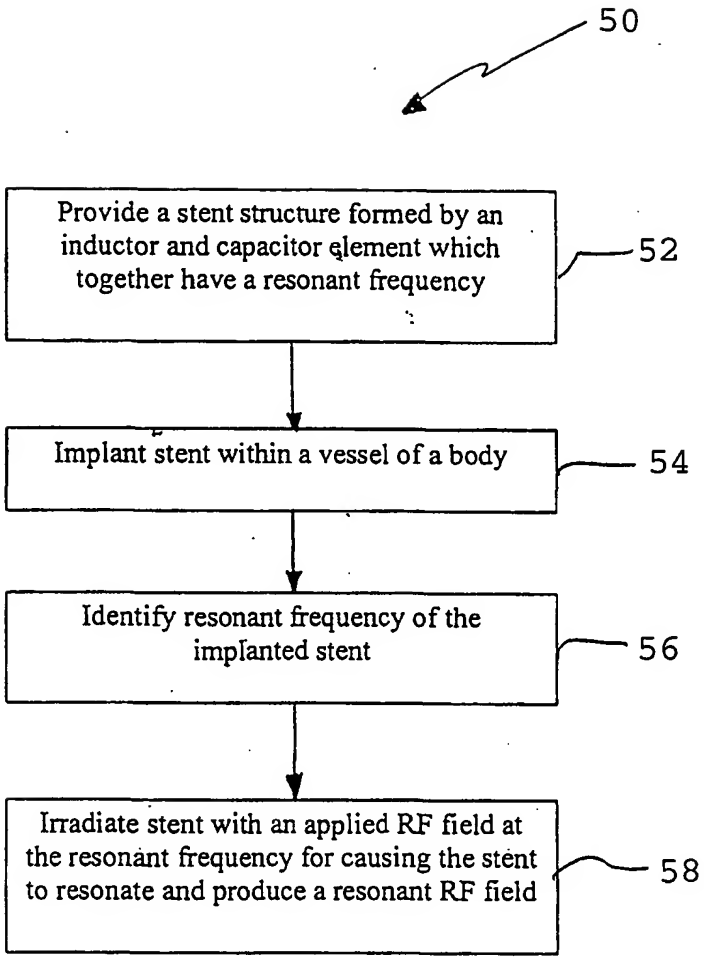
50
Provide a stent structure formed by an inductor and capacitor element which together have a resonant frequency
52
Implant stent within a vessel of a body
54
Identify resonant frequency of the implanted stent
56
Irradiate stent with an applied RF field at the resonant frequency for causing the stent to resonate and produce a resonant RF field
58

Fig. 7

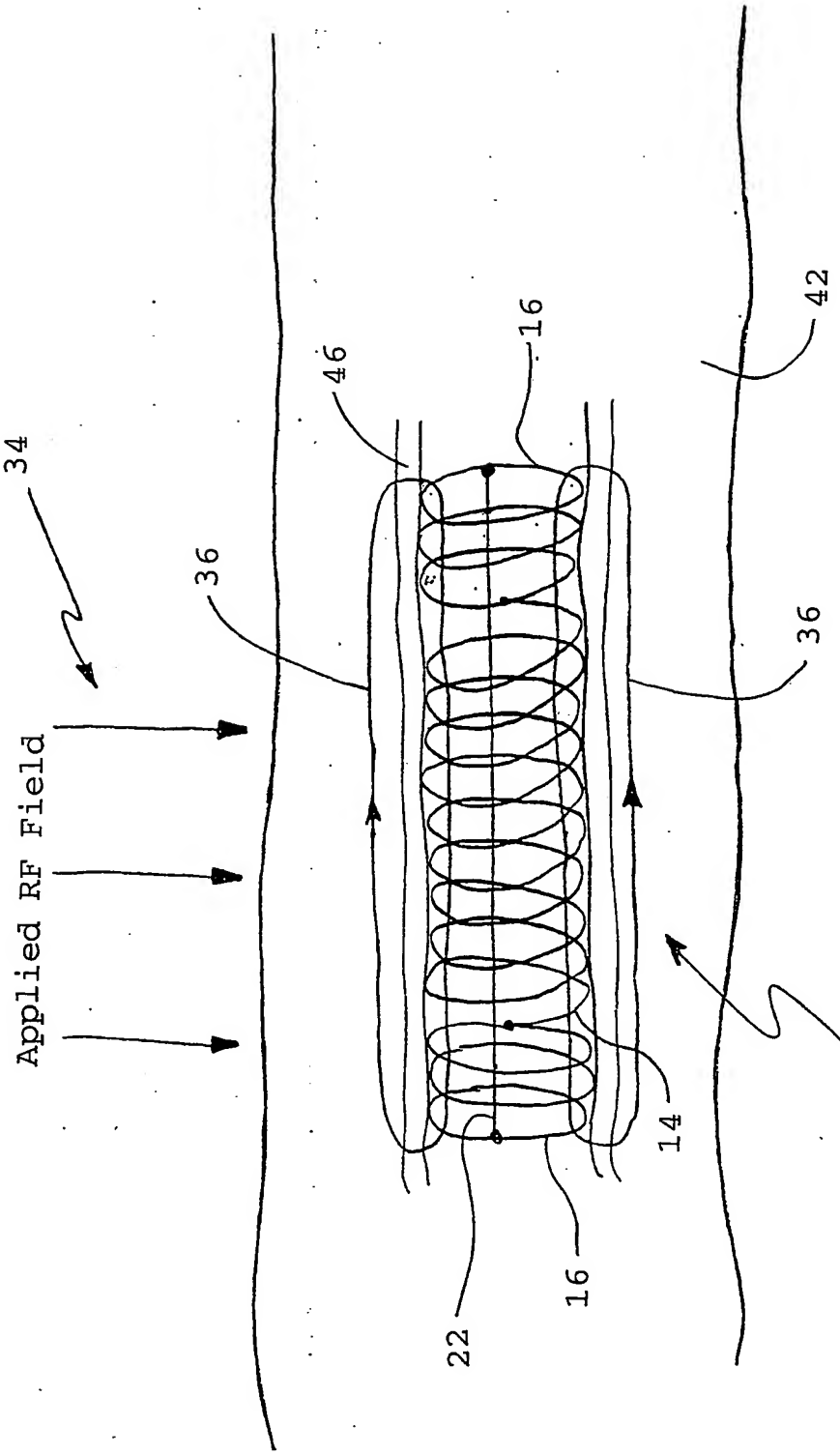

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/31906

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :A61F 2/06
US CL : 623/1.15
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 623/1.15

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, P	US 6,179,789 B1 (Tu et al.) 30 January 2001, see Figs. 1-4.	
A, P	US 6,206,835 B1 (Spillman, Jr. et al.) 27 March 2001, see Figs. 1-13.	

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 14 DECEMBER 2001	Date of mailing of the international search report 25 JAN 2002
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Form PCT/ISA/210 (second sheet) (July 1998)*